SURFACE TRANSPORT OF NUTRIENTS FROM SURFACE-BROADCAST AND SUBSURFACE-BANDED BROILER LITTER

J. Lamba, T. R. Way, P. Srivastava, S. Sen, C. W. Wood, K. H. Yoo

ABSTRACT. *Nutrient buildup, mainly phosphorus (P), and loss from fields fertilized with poultry (broiler) litter contribute to eutrophication of surface waters. In the U.S., broiler litter is typically surface-applied, but recently, to reduce surface transport of P and other nutrients, subsurface-banding of broiler litter has been promoted as a new manure application method. The objective of this study was to evaluate differences in nutrient transport between subsurface-banded and surface-applied broiler litter in a tall fescue pasture. Treatments were surface-applied and subsurface-banded broiler litter at a rate of 5.0 Mg ha^{-1}, and no application of litter (control). Results showed that runoff concentrations and loadings of total P (TP), ortho-P (PO_4-P), nitrate-nitrogen (NO_3-N), and ammonium-N (NH_4-N) were reduced by 83%, 88%, 74%, and 80%, respectively, for the subsurface-banded litter as compared to the surface-applied litter. Concentrations and loadings of all nutrients in surface runoff from the subsurface-banded treatment were similar to those from the control. This study showed that subsurface banding of broiler litter can substantially reduce nutrient losses in surface runoff. However, since less than 10% of the simulated rainfall contributed to surface runoff (more than 90% rainfall infiltrated), subsurface transport of nutrients from surface-applied and subsurface-banded litter needs to be studied in field research.*

Keywords. *Animal waste, Land application, Manure, Nitrogen, Phosphorus, Subsurface-banding, Surface runoff.*

Runoff from agriculture is a major nonpoint source (NPS) of pollution, particularly P and N pollution, for surface waters in the U.S. (Carpenter et al., 1998). The southeastern U.S. is a major area for production of broiler (*Gallus gallus domesticus*) chickens in the U.S. (USDA, 2011). The five leading broiler-producing states of Georgia, Arkansas, Alabama, Mississippi, and North Carolina produce more than 60% of all the broiler meat produced in the U.S. (Paudel and McIntosh, 2005). Broiler production, however, is currently threatened because of three main reasons: (1) rising energy costs, (2) water quality issues associated with land application of broiler litter, and (3) emerging foreign competition.

Broiler litter, which is a mixture of manure and bedding material, is commonly applied by surface broadcasting on pastures and hay fields. However, such application places nutrients on the soil surface, where they are vulnerable to transport off the field in runoff water. In addition, this practice has resulted in P accumulation in soils because of the high P-to-N ratio in broiler litter (Kingery et al., 1994). Even though P is an essential nutrient for plant growth, P loss from fields fertilized with broiler litter results in a widespread problem of eutrophication of nearby surface waters, reducing dissolved oxygen levels below the respiration requirement of fish, causing fish kills (Carpenter et al., 1998; Edwards and Daniel, 1994).

In the Sand Mountain region of northern Alabama, water quality issues associated with the massive amount of broiler litter produced each year threaten the sustainability of the poultry industry. To sustain and enhance the poultry industry in the southeastern U.S., it is critical that we urgently address the water quality issues associated with broiler production. To increase crop (and forage) yield and to reduce runoff transport of nutrients, subsurface banding of broiler litter has been tried in recent years (e.g., Pote et al., 2003; Sistani et al., 2009; Warren et al., 2008). Warren et al. (2008) determined differences in forage yield from surface-broadcasted and subsurface-banded broiler litter. Broiler litter was applied at 9.0 Mg ha^{-1} to tall fescue (*Festuca arundinacea* Schreb.) plots and bermudagrass (*Cynodon dactylon* (L.) Pers.) plots on a sandy loam soil. Subsurface-banded litter was applied using a single-band implement. Although the subsurface-banded plots received a considerable amount of traffic from the tractor and implement tires, forage yields for the subsurface-banded plots were equivalent to the plots receiving surface broadcast litter and no traffic. Further, Tewolde et al. (2009) found that

Submitted for review in October 2011 as manuscript number SW 9452; approved for publication by the Soil & Water Division of ASABE in May 2012. Presented at the 2009 ASABE Annual Meeting as Paper No. 096899.

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subsurface-band application resulted in a 7% increase in cotton (*Gossypium hirsutum* L.) lint yield and improved fiber quality, relative to surface-broadcast application of litter.

To determine the efficacy of subsurface-band application of broiler litter in reducing nutrient transport, Pote et al. (2003) manually formed 8 cm deep slits in a silt loam soil of a bermudagrass and mixed grass pasture. Broiler litter (5.6 Mg ha^{-1}) was placed in the slits, and simulated rainfall was applied at the rate of 50 mm h^{-1} to produce 20 min of runoff. Sistani et al. (2009) used subsurface-band application of broiler litter (9.0 Mg ha^{-1}) in tall fescue pasture on a sandy loam soil and applied simulated rainfall (110 mm h^{-1}) to generate 30 min of runoff. Both of these studies showed that N and P concentrations and loads were greatly reduced when subsurface banding of broiler litter was used.

Recently, a four-band implement for subsurface-band application of broiler litter in row crops and pastures was developed by the USDA-ARS National Soil Dynamics Laboratory in Auburn, Alabama (Way et al., 2010). The band spacing is adjustable from 25 to 100 cm in increments of 2.5 cm. The width of the litter band applied by the implement in the soil is about 4.5 cm, and the bottom of the band is usually about 8 cm beneath the undisturbed soil surface. The thickness of the litter band is typically about 2 cm, so the thickness of the layer of soil above the band after the implement has passed is usually about 6 cm.

Watts et al. (2011) used the four-band implement for subsurface banding of broiler litter (9.0 Mg ha^{-1}) to bermudagrass pasture on two loamy sand soils, which are common in the Coastal Plain and the Piedmont region of the southeastern U.S. Simulated rainfall was applied at 89 mm h^{-1} to generate 40 min of runoff. The researchers found that subsurface banding of litter reduced concentrations of inorganic N by 91%, total N by 90%, dissolved reactive P by 86%, and total P by 86% in runoff water, relative to surface-broadcast litter.

Although a few studies have been done (reported above) to quantify differences in N and P transport from surface-broadcasted and subsurface-banded broiler litter plots, these studies either manually formed bands for subsurface application of broiler litter or used high-intensity simulated rainfall. Manually formed bands are unable to simulate compaction of soil (both within the bands and on top of the band after litter is placed in the bands) resulting from the use of the subsurface band implement. Further, the National Phosphorus Research Project (2005) suggests that simulated rainfall-surface runoff studies should be conducted at an intensity of approximately 70 mm h^{-1} or 10-year storm for the location: "The 70 mm h^{-1} intensity is intended to permit comparisons between sites, whereas the intensity of the 10-year storm is intended to approximate local conditions" (National Phosphorus Research Project, 2005, p. 6). The litter application rates used by a few of these studies were also on the high end of the rates typically used by poultry producers in the southeastern U.S. A more realistic rate is 5 Mg ha^{-1}, as used by Pote et al. (2003). Therefore, the objective of this study was to evaluate differences in nutrient transport from subsurface-banded and standard surface-broadcasting of broiler litter in a tall fescue pasture using a realistic litter application rate, intensity of simulated rainfall, and field conditions resulting from the use of the subsurface-band implement.

Since protocols established by the National Phosphorus Research Project (2005) were followed for this study, the project generated benchmarking datasets that can be used, in conjunction with other similar studies, to conduct regional and/or national assessment of the effect of surface-applied and subsurface-banded litter on surface transport of P and other nutrients. The data can also be used to develop new or test existing P transport models, such as the one developed by Vadas et al. (2004, 2005, 2007) or the one implemented in the Soil and Water Assessment Tool (SWAT) model (Neitsch et al., 2005).

MATERIALS AND METHODS

SITE DESCRIPTION, PLOT LAYOUT, AND BROILER LITTER APPLICATION

The experiment was conducted on a Hartsells fine sandy loam (fine-loamy, siliceous, subactive, thermic Typic Hapludults) soil at the Alabama Agricultural Experiment Station's Sand Mountain Research and Extension Center at Crossville, Alabama. This soil is moderately deep (sandstone at 50-100 cm), well drained, moderately permeable, and is formed from acid sandstone (Sen et al., 2008). These soils are found on upper slopes of hills and mountains and on level to moderately steep ridges.

Runoff plots were established on permanent 'Kentucky 31' tall fescue pasture. The grass was mown to a height of 10 cm, and the clipped grass was removed from the plots. Protocols established by the National Phosphorus Research Project (2005) were used in constructing the plots and performing rainfall simulations. Nine plots, each 1.52 m wide and 3.05 m long, were established. Each plot had a slope of 4%, and the long axis of the plot was parallel to the slope. Galvanized steel sheet metal borders (10 cm belowground and 10 cm aboveground) were used to keep surface water within each plot. A galvanized steel sheet metal trough was installed at the downslope end of the plot to collect surface runoff and direct it to a collection point at the corner of the plot.

The two methods of broiler litter application compared in this experiment were surface-broadcast application and subsurface-band application, both at 5.0 Mg ha^{-1}. The litter used in the experiment was wood shavings-based litter. Surface-broadcast litter was applied manually. Subsurface-band application was accomplished using a device (fig. 1) that applied litter in subsurface bands similarly to a prototype implement developed by the USDA-ARS National Soil Dynamics Laboratory (Farm Show, 2009; Way et al., 2010). On each subsurface-banded plot, nine subsurface band trenches about 5 cm deep and 4 cm width were made, with each trench extending across the width of the plot, perpendicular to the slope (fig. 2). These trenches were spaced at 30.5 cm intervals. The appropriate amount of broiler litter for each plot was calculated, and one-ninth of that total was placed by hand in each trench and evenly distributed in the trench. Soil that had been heaved up along the sides of each trench when the trench was formed was then pressed back in on the top of the trench, thereby covering the litter band with

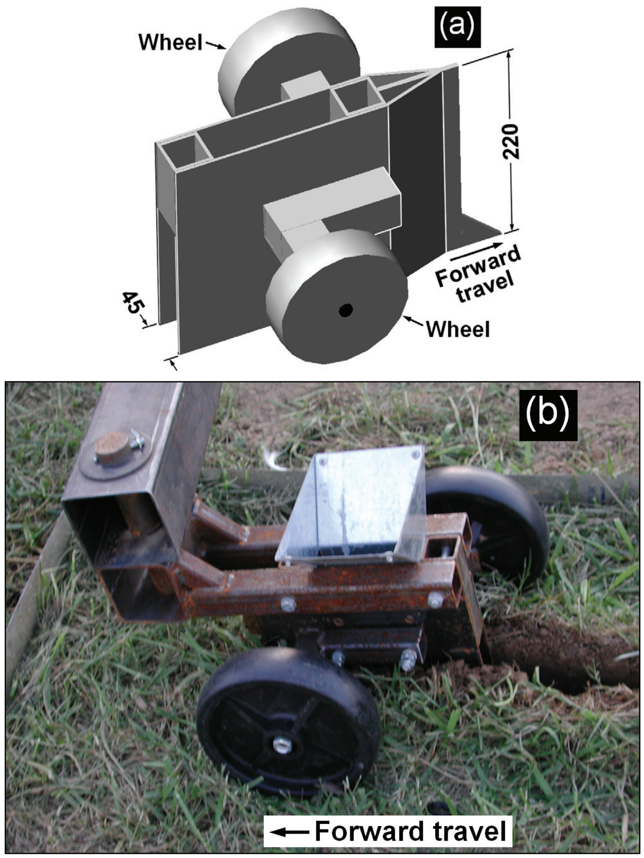

Figure 1. Subsurface banding device used to make trenches in plots for subsurface band application of broiler litter: (a) right side view (dimensions are in mm) and (b) left side view of device in soil.

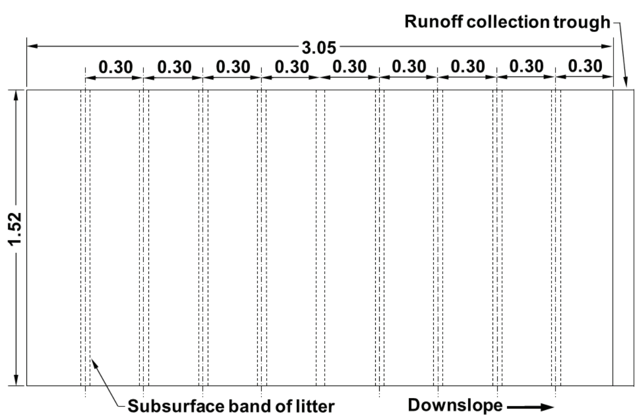

Figure 2. Top view of a subsurface-banded plot (dimensions are in m). The 3.05 m × 1.52 m plot dimensions were also used for the surface broadcast litter plots and the control plots.

about 3 cm of soil to prevent any direct contact between surface runoff water and the broiler litter. An additional treatment was an unfertilized control treatment.

Rainfall Simulation

Timing of litter application relative to runoff-producing rainfall has a significant impact on P loss in surface runoff (Sistani et al., 2009; Schroeder et al., 2004). As the elapsed time between litter application and runoff-producing rainfall increases, P loss in surface runoff decreases. In this study, rainfall simulations were conducted immediately after litter application, as we wanted to consider a worst-case scenario. A rainfall simulation was conducted on each plot at an intensity of 70 mm h^{-1}, as suggested by the National Phosphorus Research Project (2005). The rainfall simulator had a TeeJet 1/2 HH-SS50WSQ nozzle (Spraying Systems Co., Wheaton, Ill.) 305 cm above the soil surface, positioned above the center of the plot. Starting at 2.5 min after the start of runoff, twelve 1 L runoff samples were collected, one sample every 5 min, providing samples representative of the first 1 h of runoff. The runoff flow rate was estimated by recording the time to fill a 1 L sample bottle. The total runoff volume from each plot was collected. The volume of water infiltrated into the soil was determined by subtracting the total runoff volume from the volume of rainfall applied to the plot during the rainfall simulation period. Immediately after runoff sample collection, samples were stored at 4°C until they were analyzed. To determine background nutrients in the water, a sample of source water flowing from the simulator nozzle was collected during each simulation.

Sampling and Statistical Analysis

Before application of broiler litter, three baseline soil samples were collected at the 0-5 cm depth range for each plot. These samples were collected 2 to 3 cm outside the sheet metal borders so that the hydrology of the plots would not be disturbed. The samples were analyzed, and mean values from the analyses were calculated. Chemical characteristics of the 0-5 cm soil layer are shown in table 1. The soil samples were analyzed for pH, Mehlich-1 extractable P (M1-P), PO_4-P, total N (TN), ammonium N (NH_4-N), and nitrate N (NO_3-N). Broiler litter used for the experiment was collected from a local broiler house. Samples of the broiler litter were collected before litter application to the plots and stored in plastic bags at 4°C until analyzed. These samples were analyzed for water content, pH, electrical conductivity (EC), TN, TP, NH_4-N, NO_3-N, and PO_4-P (table 2).

The soil samples collected were analyzed for nutrients in the Nitrogen Laboratory of the Department of Agronomy

Table 1. Selected properties of soil on a dry weight basis, for the 0-5 cm depth before litter application.

Parameter	Value[a]
pH	5.13 (0.02)
NH_4-N (mg kg^{-1})	21.59 (0.67)
NO_3-N (mg kg^{-1})	13.22 (0.79)
TN (%)	0.14 (0.19)
M1-P (mg kg^{-1})	37.37 (0.45)
PO_4-P (mg kg^{-1})	4.61 (0.67)

[a] Means of 27 samples (coefficients of variation in parentheses).

Table 2. Composition of broiler litter applied to tall fescue pasture plots.

Parameter	Value
pH	8.7
NH_4-N (mg kg^{-1}, dry weight basis)	1203
NO_3-N (mg kg^{-1}, dry weight basis)	111
TN (%, dry weight basis)	2.9
TP (mg kg^{-1}, dry weight basis)	19280
PO_4-P (mg kg^{-1}, dry weight basis)	3114
Water content (% wet basis)	25.9
EC (S m^{-1})	0.086

and Soils at Auburn University. Soils were dried at 60°C for 48 h and sieved through a 2 mm sieve before analysis. Soil NH_4-N and NO_3-N were extracted with 2 M KCl (Keeney and Nelson, 1982) and analyzed using the microplate procedure (Sims et al., 1995). For M1-P measurement, 5 g of a sample was extracted with 20 mL of a dilute double acid mix of 0.05 N HCl and 0.025 N H_2SO_4 (Hue and Evans, 1986) prior to analyses via inductively coupled argon plasma (ICAP) spectroscopy (Spectro Ciros CCD, side-on plasma, Spectro Analytical Instruments GmbH, Kleve, Germany).

One gram of broiler litter was extracted with 25 mL of 2 M KCl for determination of NH_4-N and NO_3-N. Total P in the litter was determined using the dry ashing method (Hue and Evans, 1986) followed by ICAP spectroscopy. Broiler litter and soil were analyzed for total N by dry combustion (TruSpec CN, Leco Corp., St. Joseph, Mich.). Measurements of pH were done for soil (1:1 soil:water) and broiler litter (1:3 litter:water) using a pH meter (model UB-5, Denver Instrument Co., Arvada, Colo.).

Water samples filtered with 0.45 μm filters were analyzed for NH_4-N, NO_3-N, and PO_4-P, while unfiltered water samples were analyzed for TP. NH_4-N and NO_3-N were measured on filtered water samples using the microplate procedure (Sims et al., 1995). PO_4-P was measured colorimetrically on water filtered through a 0.45 μm membrane (Murphy and Riley, 1962). For TP analysis, 25 mL of unfiltered water sample was digested with 10 mL of wet ash acid mix (70:30 nitric:perchloric acid) (John, 1972) prior to analysis by ICAP spectroscopy. In this study, all the nutrient concentrations in surface runoff are defined as the flow-weighted nutrient concentrations (i.e., mass of nutrient loss in 1 h of runoff divided by total volume of runoff during that hour). Mass loss (loading) in runoff was calculated by multiplying the concentration of each discrete sample and the corresponding flow volume, and summing these incremental loads for the full runoff duration.

The experimental design was a completely random design with three replicates. Analyses of variance were done using PROC GLM in SAS (SAS, 1999). The least significant difference (LSD) was used to separate means at the $\alpha = 0.05$ significance level.

Table 3. Flow-weighted concentrations of selected constituents in surface runoff from control, surface-applied, and subsurface-banded litter plots.

	Litter Treatment[a]			
Runoff Constituent	Control (mg L^{-1})	Surface-Applied Litter (mg L^{-1})	Subsurface-Banded Litter (mg L^{-1})	Treatment p-Value
NH_4-N	0.43 a	1.67 b	0.33 a	0.0052
NO_3-N	0.40 a	3.25 b	0.83 a	0.0104
PO_4-P	0.37 a	3.43 b	0.42 a	0.0060
TP	0.69 a	6.01 b	1.02 a	<0.0001

[a] Within each row, means followed by the same letter are not significantly different at $\alpha = 0.05$ (LSD).

Results and Discussion

Runoff Concentration

The average time necessary to generate runoff from the plots was about 40 min. The mean flow-weighted concentrations of nutrients analyzed in surface runoff were strongly affected by broiler litter application method (table 3). Nutrient concentrations were significantly greater in the runoff from surface-applied litter plots in comparison with the subsurface-banded litter and control plots. Total P and PO_4-P concentration were reduced by 83% and 88%, respectively, in surface runoff when broiler litter was subsurface-banded compared to surface-applied litter. The TP concentration followed the same trend as PO_4-P concentrations in all treatments. Our data show that PO_4-P is the dominant form of TP in surface runoff from tall fescue pasture. Similarly, Nichols et al. (1994) reported that PO_4-P constitutes more than 50% of TP in surface runoff from surface-applied litter plots and plots in which litter was incorporated 2 to 3 cm deep by rotary tillage.

Similar to the findings of Pote et al. (1999), Sharpley (1995), and Sharpley et al. (1994), mean concentrations of TP and PO_4-P were found to be positively correlated to the soil test P levels (as measured by Mehlich-1 P) in the control plots (fig. 3a). That is, as the soil test P increased in the control plots, so did the concentrations of TP and PO_4-P in surface runoff. The relationship of soil test P with concentrations of TP and PO_4-P seems to diminish when subsurface banding of broiler litter was used (fig. 3b). This could be because concentrations of TP and PO_4-P are at least partially affected by subsurface-banded broiler litter. Soil test P and runoff concentrations of TP and PO_4-P from surface-

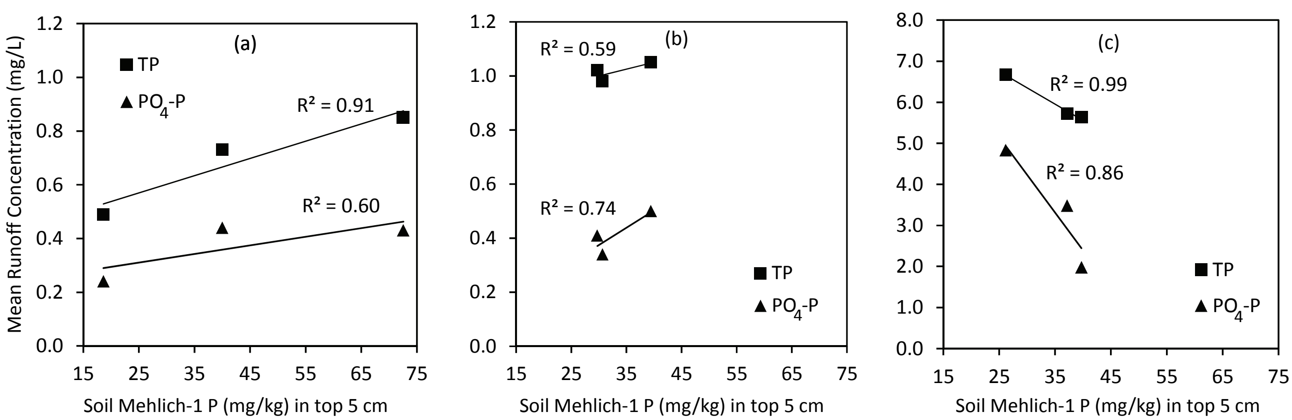

Figure 3. Event mean TP and PO_4-P concentrations in surface runoff from (a) control, (b) subsurface-banded, and (c) surface-applied plots as affected by soil test P (Mehlich-1 P) in top 5 cm of soil.

applied plots were found to be negatively correlated (fig. 3c). That is, concentrations of TP and PO_4-P in surface runoff from surface-applied plots were affected chiefly by the litter on the surface, and the effect of soil test P (if any) was minimal. This finding is consistent with the finding of Vadas et al. (2007), which suggests that dissolved P release from surface-applied, unincorporated manures and its transfer to runoff during a rain event is from the litter layer if the rainfall event occurs soon after the litter application.

Subsurface-band application of litter also reduced the N concentration in surface runoff. Ammonium-N and NO_3-N concentrations were reduced by about 80% and 74%, respectively, in surface runoff from subsurface-banded litter plots in comparison with surface-applied plots (table 3). The results were similar to those found by Pote et al. (2003) and Watts et al. (2011). Concentrations of all nutrients in subsurface-banded litter plots were very close to those of the control plots; there were no significant differences found in nutrient concentrations between control and subsurface-banded litter plots. The nutrient concentration results show that subsurface-band application of litter proved to be a better method to control nutrient concentrations in surface runoff than surface-broadcast application of litter. This is because subsurface-band application of litter prevents direct contact between the broiler litter and surface runoff, as surface runoff water interacts with the top few cm of soil. A previous study by Sharpley (1985) showed that the effective depth of interaction between surface soil and surface runoff is about the upper 2.5 cm of soil at 70 mm h^{-1} rainfall intensity.

MASS LOSS IN SURFACE RUNOFF

The mean loading of runoff constituents, i.e., TP, PO_4-P, NH_4-N, and NO_3-N, was significantly greater for the surface-applied litter than for the subsurface-banded litter and control plots (figs. 4 and 5). There was no significant difference found in loading of TP and PO_4-P between the control and subsurface-banded litter plots. The TP loading in surface runoff was reduced by 83% and the PO_4-P loading was reduced by 88% for subsurface-banded litter compared to surface-applied litter. In a similar study, Sistani et al. (2009) found that loading of nutrients in surface runoff water was significantly less when broiler litter was applied in subsurface bands compared to surface-broadcast litter. However, they found that TP loading in surface runoff 1 d after broiler litter application was much greater than in our study. Considering absolute values of TP losses, the TP losses reported by Sistani et al. (2009) were about 80% more for surface-applied litter and about 50% more for subsurface-banded litter, compared to the corresponding TP losses from our study. This may have been caused by the greater 9.0 Mg ha^{-1} application rate used by Sistani et al. (2009), compared to the 5.0 Mg ha^{-1} used in our study. In addition, the rainfall intensity used by Sistani et al. (2009) was 110 mm h^{-1}, and this may have caused a greater loss of broiler litter in the runoff water compared to our study, which had a 70 mm h^{-1} rainfall intensity. The TP loss in surface runoff was about 0.6% of the TP applied through litter application for the surface-applied litter and about 0.1% for the subsurface-banded litter. This shows that even in the worst-case scenario of a rainfall event immediately after litter application, TP losses in surface runoff are a small fraction of the TP in the applied litter.

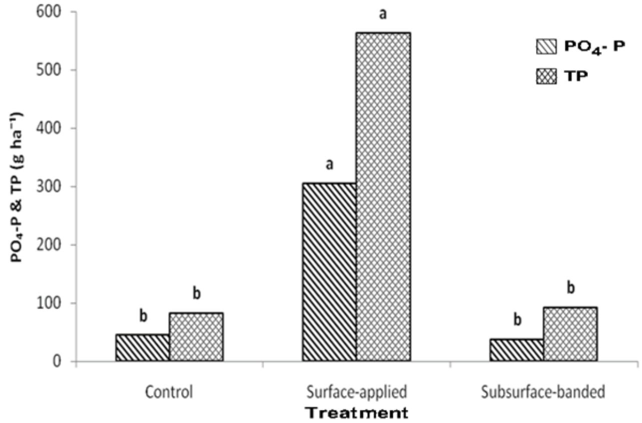

Figure 4. PO_4-P and TP loading in surface runoff from control, surface-applied, and subsurface-banded litter plots. Within each nutrient, bars with the same letter indicate no significant difference between treatments at $\alpha = 0.05$ (LSD).

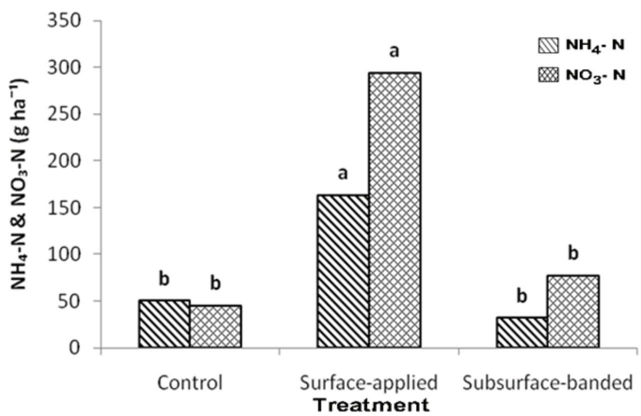

Figure 5. NH_4-N and NO_3-N loading in surface runoff from control, surface-applied, subsurface-banded litter plots. Within each nutrient, bars with the same letter indicate no significant difference between treatments at $\alpha = 0.05$ (LSD).

The NO_3-N loading in surface runoff was reduced by 74% and the NH_4-N loading was reduced by 81%, for subsurface-banded litter compared to surface-applied litter. For both NO_3-N loading and NH_4-N loading, there was no significant difference between the subsurface-banded litter and the control plots. Significant differences in loading of nutrients are difficult to detect in field experiments. This is because loading is the product of runoff volume and the mean concentration of that constituent in the runoff. Each of these factors has considerable variation in field situations, so this results in greater variation in their product. However, in our case, the product of runoff volume and mean concentration was less for the subsurface-banded litter treatment and the control treatment than for the surface-applied litter treatment. Although there was no significant difference in runoff volume among the three treatments, the concentration of nutrients in the runoff of the subsurface-banded litter and control plots was significantly less than for the surface-applied litter plots. This decrease in the concentration of nutrients decreased the product of runoff vol-

Table 4. Water budget for the experiment showing amount of rainfall applied, runoff generated, volume of water infiltrated, and percentage of rainfall which contributed to runoff and infiltration.

	Litter Treatment[a]		
	Control	Surface-Applied Litter	Subsurface-Banded Litter
Rainfall (m^3)	0.56 a	0.51 a	0.58 a
Runoff (m^3)	0.05 a	0.04 a	0.04 a
Infiltrated (m^3)	0.51 a	0.46 a	0.53 a
Proportion of rainfall converted to runoff (%)	8.9	7.8	6.9

[a] Within each row, means followed by the same letter are not significantly different at $\alpha = 0.05$ (LSD).

ume and concentration. Therefore, significant differences were observed in loading between the treatments, and in our case the trend followed the same trend exhibited by the concentrations.

Water Budget

The water budget of the experiment is shown in table 4. The percentage of rainfall that contributed to 1 h of runoff was less in plots with subsurface-banded litter in comparison with the control and surface-applied litter plots. The likely reason is that some water was absorbed by the broiler litter in the subsurface bands and some of the water stayed in the trenches where the banded litter was applied. For the control plots, a greater percentage of rainfall contributed to surface runoff than for the surface-applied litter plots, as the control plots had neither broiler litter nor trenches. The percentage of rainfall that contributed to surface runoff for the surface-applied litter plots was between that of the control and that of the subsurface-banded litter plots. These surface-applied and control plots were without trenches, and this likely caused a greater percentage of rainfall to contribute to surface runoff compared to the subsurface-banded litter plots. Some water for the surface-applied litter plots may have been absorbed by the litter, resulting in a smaller percentage of rainfall contributing to surface runoff than for the control plots. Although the mean volume of rainfall applied and the mean volume of runoff varied slightly among treatments, these differences were not significant (table 4). Irrespective of treatment, results showed that less than 10% of the rainfall contributed to surface runoff. This result supports the finding by Sen et al. (2009) that in pastures of the Sand Mountain region of northern Alabama, less than 10% of the rainfall contributes to surface runoff. In all plots, more than 90% of the rainfall infiltrated the soil. This suggests that significant subsurface flow may occur in this region, irrespective of treatment. Therefore, transport of nutrients via subsurface flow might be important in this region.

Conclusions

The results of this study indicate that the method of litter application plays an important role in determining concentration and loading of nutrients in surface runoff water. Runoff from surface-applied litter had higher concentrations of nutrients in comparison with subsurface-banded litter. Subsurface-band application of litter decreases direct contact between broiler litter and surface runoff water, so the runoff nutrient concentrations from subsurface-banded litter were very similar to those of the control, with no statistical differences. The trend for loading of various nutrients in runoff was similar to the trend for concentration in runoff. Loading of nutrients in runoff from surface-applied litter plots was greater than from subsurface-banded litter plots, but loading of nutrients from subsurface-banded litter was no different than from control plots. Our water budget results showed more than 90% of the rainfall infiltrated this sandy loam soil, which suggests that there may be significant subsurface flows. Therefore, subsurface transport of nutrients may be important in this soil, and future studies should be conducted to quantify nutrient loss via subsurface flows. The benchmarking datasets generated by this study can be used, in conjunction with other similar studies, to conduct regional and/or national assessment of the effect of surface-applied and subsurface-banded litter on surface transport of P and other nutrients. These data are also useful for developing new P transport models or testing existing models.

Acknowledgements

The project was supported by the Natural Resources Initiative grant program of the Alabama Agricultural Experiment Station. We gratefully acknowledge Marlin R. Siegford, Brenda H. Wood, and Anand K. Gupta for their technical assistance in this research.

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